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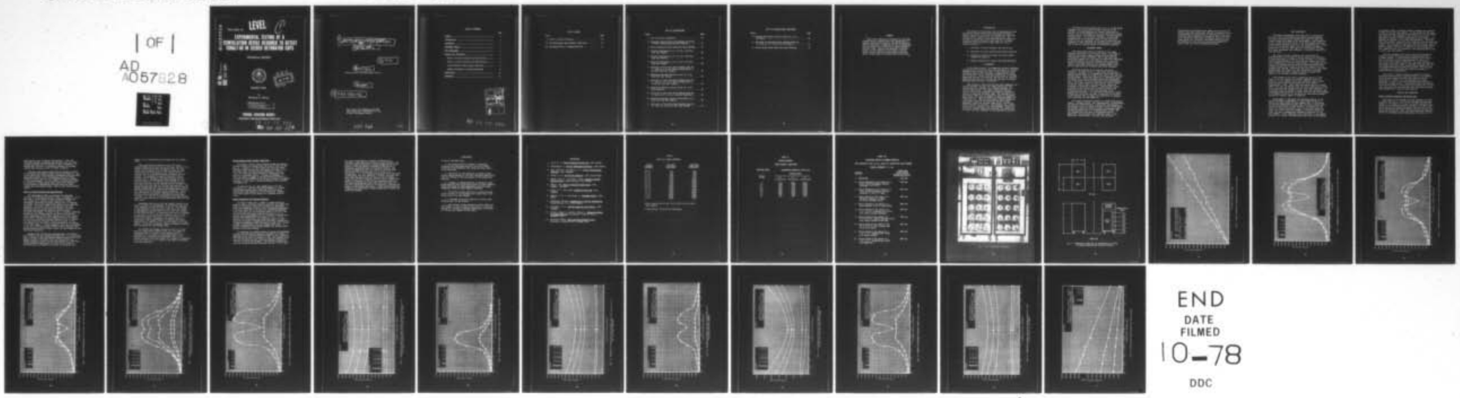

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EXPERIMENTAL TESTING OF A SCINTILLATION DEVICE DESIGNED TO DETECT COBALT-60 IN SEEDED DETONATOR CAPS

TECHNICAL REPORT

MARCH 1965

by
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FEDERAL AVIATION AGENCY
AIRCRAFT DEVELOPMENT SERVICE

6 EXPERIMENTAL TESTING OF A SCINTILLATION DEVICE
DESIGNED TO DETECT COBALT-60 IN SEEDED DETONATOR CAPS.

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Systems Research and Development Service

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SUMMARY

Tests were conducted to determine the operating characteristics, capabilities, and limitations of a nuclear scintillation detection system developed by Catholic University of America for use in conjunction with the detection of Cobalt-60 in seeded explosive detonator caps. Results were generally favorable except for the inability of the device to detect rapidly moving sources and the relative ease with which a source might be shielded from the detector.

INTRODUCTION

The purpose of this project was to experimentally test the nuclear scintillation detection system developed by Catholic University of America to determine its operating characteristics, capabilities, and limitations. The accuracy of the device in detecting radioactive Cobalt-60 in seeded explosive detonator caps under the following conditions shall ascertain to what extent it will be further utilized:

1. Variation in source intensity and source type.

2. Variation in source position and detector position.

3. Variation in speed with which the source passes through the detector.

4. Signal attenuation by various shielding materials.

BACKGROUND

In the United States, five commercial aircraft disasters resulting in 214 fatalities have been attributed to inflight bombing during the past ten years. There have been other incidences where airline sabotage was suspected but could not be verified. Since intentional destruction of inflight commercial aircraft has occurred, the need for an effective bomb detection device to preclude the carrying of infernal machines aboard aircraft is warranted.

Many methods of bomb detection have been suggested, but few are foolproof and most are judged impractical when considering their economic cost, evident drawbacks, or limited capabilities. One method considered feasible involves the use and subsequent detection of radioactive tracers in explosive detonator caps. The desirability of this method stems from the generality that all "homemade" bombs consist of explosive powder, a timing mechanism, and a detonator cap. The explosive powder, usually dynamite, can be easily procured or concocted, and the timing mechanism, usually an ordinary alarm clock, can also be easily obtained and modified. The detonator cap, however, is difficult to produce in the home workshop. Since the Interstate Commerce Commission regulates its manufacture, it offers the best container for the radioactive material.

The Federal Aviation Agency and the U. S. Atomic Energy Commission in a joint effort issued a contract to the Division of Nuclear Engineering, Catholic University of America, for the development of a device which would detect a minute amount of radioactive material in seeded explosive detonator caps. The technical, economic, and practical acceptability of a detection system of this type would result in its use nationally at all major airports and the enactment of laws requiring all manufacturers of detonator caps to add the required amount of radioactive material.

EQUIPMENT TESTED

The scintillation device consisted of four large detection units each 73 by 30 by 27 inches. The frame of each unit was made of angle aluminum, and the exterior covering was of sheet aluminum. Two of the units were positioned adjacent, and the other two units were positioned in the same manner but on the opposite side of the test channel. The lower portions of the units contained the liquid scintillator tanks and the photomultiplier tubes, and the upper portions contained electronic equipment.

The lower sections of the detector units were identical. As shown in Fig. 1, the liquid scintillator, decalin, is contained in a transparent lucite tank, and 15 photomultiplier tubes are fixed to the side of the tank with silicon grease. Gamma rays emitted by a radioactive source are picked up by the scintillator liquid and transformed into light pulses which are detected by the photomultiplier tubes. The lower section of each detector unit is sealed to prevent outside light from entering the system and producing an erroneous excitation. Aluminum foil covers a portion of each lucite tank in order to reflect and therefore retain most of the light produced in the scintillation process. A 1-inch thick lead slab is located between the lucite tank and wall of each unit on the side of the adjacent tank to reduce the possibility of adjacent tanks detecting the same gamma ray.

The system electronics consist of a single high-voltage supply, a voltage divider, four preamplifiers, two amplifiers, two low-level discriminators, a high-level discriminator, a coincidence circuit, a count rate meter, and an alarm system. The voltage supply and divider provide the necessary high voltage for each group of 15 photomultiplier tubes. The four preamplifiers are used in conjunction with two amplifiers, each amplifying the combined output of two diagonally located tanks. The high- and low-level

discriminators distinguish which gamma rays are given off within a specified energy band, and the coincidence circuit distinguishes which are given off simultaneously for the count rate meter reading to be primarily that of Cobalt-60 as differentiated from other radioactive materials. The alarm system, not utilized in the NAFEC testing program, was connected to the count rate meter and buzzed if a preset count rate meter reading was exceeded.

TEST PROCEDURES

Preliminary measurements were made prior to testing the system to check its calibration and assure optimum response. The liquid scintillator was flushed with argon to remove any trapped oxygen which might affect performance. The calibration of each of the four detection units was then checked using the single-channel analyzer in place of the coincidence unit. Thereafter the coincidence trigger level was checked followed by calibration of the low- and high-level discriminator settings. Only minor adjustments were necessary to bring the system up to peak operation.

The effect of source intensity was then studied by suspending Cobalt-60 sources of various radioactive intensity, 0.1-microcurie (μc) to 1.5-μc in 0.1-μc intervals, at a central location between tanks B & C and noting the average count rate meter reading over a 1-minute time interval. The count rate was corrected by subtracting the average background reading (that reading obtained with no source in the test channel) from the average total reading. This method was used with all four tanks operating and with tanks B & C only operating to determine whether count rate meter reading variation is linear with respect to an increase in source intensity.

Since radium in the form of luminescent watch or clock dials is the only radioactive material commonly found on a person or in his luggage, tests were conducted using a 0.2-μc Cobalt-60 source and a large radium dial alarm clock of approximately 1.5-μc. Both items were placed centrally between tanks B & C, and the average count rate meter reading was studied over a 1-minute time interval with all four tanks operating. It is unlikely that the average traveler would carry personal items containing radium in excess of 1.5-μc, and this test was performed to determine the ability of the device to discriminate between radium and a smaller amount of Cobalt-60.

Measurements to determine the operating envelope of the device were made by suspending a 1.0-μc Cobalt-60 source at various positions within the test channel (Fig. 2) and noting the average background-corrected count rate meter rading over a 1-minute time interval at each position. Utilizing all four units, the source was placed at each of 231 points along the center of a 2-foot wide test channel to determine whether the count rate meter readings were repeated in each half of the test channel. After operation of the two halves of the channel proved to be similar, 484 additional points were tested between

two opposite tanks to determine whether readings were repeated on each side of the test channel. It was found that the count rate meter readings obtained in one quadrant of the test channel were similar to the readings in each of the other three quadrants; therefore, further measurements were limited to one quadrant and applied to the other three quadrants. Using the same 1.0-μc source, tests were then conducted using two tanks and a 2-foot wide test channel, and four tanks and a 4-foot wide test channel. Since 0.2-μc is considered to be the maximum desired source intensity for use as a radioactive tracer, tests were also conducted using this intensity, four operating units, and a 2-foot wide test channel.

The time response of the system for moving sources was studied for three different source intensities and eight different speeds. A variable speed conveyor was set up so that an unshielded source passed through the center of a 2-foot wide test channel at X=0 Z=30. For each intensity, the source was passed through at the same speed ten times and the maximum count rate meter reading during passage with all four tanks operating was noted and averaged. This was done to determine if a relatively high speed is necessary to render the source undetectable.

The effect of signal attenuation caused by shielding radioactive Cobalt-60 with various materials was studied to determine what common materials might shield a source sufficiently to permit it to pass through the detector unnoticed. A total of ten test conditions were studied in tests with a 0.2-μc source. The shielded source was located at X=0 Y=-15 Z=30 in a 2-foot wide test channel with all four tanks operating, and the resulting count rate meter reading was averaged over a 1-minute time interval.

RESULTS AND DISCUSSION

Effect of Source Intensity and Source Type

The effect of an increase in source intensity is noted in Table I and Fig. 3. In both the two-tank and four-tank operation, the count rate is seen to increase linearly with respect to an increase in source intensity. The data points do not fall exactly along the linear line, but this is due partly because the individual sources used may not have been accurately calibrated. Also, the count rate meter reading used is the average reading obtained for the source in the

same position over a 1-minute time interval. Since the difference between the maximum and minimum count rate meter reading increases with an increase in source intensity, it becomes more difficult to accurately estimate the average reading when testing a source of higher intensity.

The tests with radium showed that the detector is able to accurately discriminate between radium and Cobalt-60. The 1.5-μc radium dial clock produced a background-corrected count rate meter reading of 670 counts/minute while the 0.2-μc Cobalt-60 source resulted in a background-corrected reading of 3940 counts/minute. In other words, a radium source with an intensity 7½ times greater than a particular Cobalt-60 source produced a background-corrected count rate meter reading only one-sixth as large. This is well within desired limits.

Effect of Source Position and Tank Position

The measurements taken to determine the operating envelope of the device are shown in Figs. 4 through 15. It is seen that a 1.0-μc Cobalt-60 source traveling through the test channel at a constant X and Z position, a likely assumption, experiences a maximum reading prior to reaching the center of the test channel (Y=0) when all four tanks are operating. The value at Y=0 is considerably less than maximum at the face of the detector because of the lead shielding between adjacent detectors which partially attenuates the signal. As shown in Fig. 4, a source traveling through the test channel against the face of the detector (X=12) experiences a much lower reading at Y=0 than a source which travels through the test channel closer to the center. It should be noted that readings obtained at X=6, a location half way between the detector face and the center of the test channel, are very close to those obtained at the center of the test channel. In most instances, the count rate reading at the end of the test channel (Y=30) is about one-third the maximum reading obtained farther inside the test channel at the same X and Z position.

Assuming that the vertical scanning area of the device was limited to the area between Z=12 and Z=54, it is noted from Figs. 4 through 6 that the maximum reading obtained in the test channel occurs at X=12 Z=30, and the curve on which the maximum reading is lowest for the test channel is at X=0 Z=54. Curves passing through points X=12 Z=30 and X=0 Z=54 are therefore used to illustrate the effect of decreasing the

number of units operating and increasing the test channel width.

When operating with opposite units B & C only, a maximum reading occurs only once in the test channel at the center of the units (Y=-15), as shown in Fig. 10. The values plotted between Y=15 and Y=30 are those obtained between Y=15 and Y=-60 using a 1.0-μc source and are included only to illustrate readings throughout the test channel. The readings for negative values of Y would actually be less because of the lead shielding between adjacent tanks. The maximum X=12 Z=30 reading for the two-tank operation is 23 percent less than that for the four-tank operation, and the maximum X=0 Z=54 reading is 28 percent less than that for the four-tank operation. The biggest disadvantage with the two-tank operation is that in passing through the test channel the maximum reading occurs only once and falls off quite rapidly thereafter. In the four-tank system, the maximum reading occurs twice and a satisfactorily high reading is maintained between these two peaks. As a result, a moving source has a much greater chance of being detected by a four-tank system than by a two-tank system.

Increasing the width of the test channel results in an overall decrease in the magnitude of the various count rate meter readings, as shown in Figs. 12 and 13. The reading at the X=24 Z=30 Y=-12 position for the 4-foot test channel is approximately one-half that for the 2-foot test channel at X=12 Z=30 and Y=-12. It should be noted that the readings in the center of the 4-foot test channel at X=0 Y=-12 are approximately one-fourth those at the same points in the 2-foot test channel. Therefore, the overall effect of doubling the test channel width is a decrease in detector sensitivity by a factor of 4 to 1 at the center of the test channel. There was no apparent change in background reading when increasing the test channel width.

The maximum and minimum traverse curves for a 0.2-μc source of Cobalt-60 are shown in Fig. 14. The signal-to-background count rate ratio for the minimum curve is approximately 5 to 1 which is sufficiently high for the detection of a stationary and unshielded source. The maximum reading in the test channel has a signal-to-background count rate ratio of 11 to 1 which is well above that needed for source detection.

System Response Under Dynamic Conditions

The speed at which a source passes through the detector adversely limits its capabilities, as shown in Table II and Fig. 16. A speed of 1.5 fps reduces the count rate meter reading by more than one-half, and speeds in excess of 2.0 fps would render a 0.2-μc source undetectable. Even at 1 fps, the count rate meter reading is considerably less than for a stationary source. It would be necessary to limit the speed of baggage traveling through the device or to modify the electronics of the system to improve its dynamic response, if this type of detection equipment were intended for general use.

As noted in Fig. 16, test speeds were at 0.2 fps intervals up to 1 fps and after establishment of a linear relationship between source speed and count rate meter reading were then reduced to 0.5 fps intervals. Dynamic tests were limited by the conveyor to a maximum speed of 2 fps.

Signal Attenuation By Various Materials

As shown in Table III, a number of common materials might be used to partially shield a detonator cap seeded with 0.2-μc of radioactive Cobalt-60 and bring its detectable count rate dangerously close to that of background radiation. At the test point X=0 Y=-15 Z=30, the signal-to-background count rate ratio for the unshielded source is 9.5 to 1, but the first test using water reduced this value to 3 to 1. Another test using magazines as the attenuator resulted in a signal-to-background count rate ratio of 5 to 1. It is possible for a stationary and unshielded source of 0.2-μc Cobalt-60 to produce a maximum count rate meter reading with a signal-to-background count rate ratio of only 5 to 1 in the minimum traverse path of the test channel (X=0 Z=54). A partially shielded source moving through this traverse would produce a much lower reading.

To determine the combined effect of motion and shielding, a 0.2-μc Cobalt-60 source partially shielded by 6 inches of magazines on all sides was passed through the test channel at X=0 Z=30 and X=0 Z=54 at a speed of 1 fps. The maximum count rate meter reading achieved during ten passes through each traverse was noted and averaged. The X=0 Z=30 traverse produced an average background-corrected reading of 1190 counts

per minute (cpm) against a maximum of 4320 cpm for a stationary unshielded source within the same traverse. The X=0 Z=54 traverse produced an average background-corrected reading of 490 cpm against a maximum of 1870 cpm for a stationary unshielded source in the same traverse. The signal-to-background count rate ratios for the X=0 Z=30, and the X=0 Z=54 traverses were 3.4 to 1 and 2 to 1, respectively. A 2 to 1 signal-to-background count rate ratio is definitely less than desirable. In fact, the count rate meter read 700 cpm or less for three of the ten passes through the X=0 Z=54 traverse, and this value is within the range of fluctuation of the 500 cpm background radiation. Any signal-to-background count rate ratio less than 3 to 1 would be undesirable because of the necessity of setting the system to alarm above that value. A lower setting would not eliminate the possibility of false alarms due to radium dial clocks and watches.

CONCLUSIONS

It may be concluded that:

1. The device tested is capable of detecting a stationary and unshielded source of as low as 0.2-μc Cobalt-60 as discriminated from radium and other radioactive materials.

2. The device is less sensitive to rapidly moving sources passed through it, but this limitation might prove less of a problem if the electronics of the system were modified.

3. A number of common materials of relatively light weight might be used to partially shield a 0.2-μc Cobalt-60 source and render it indistinguishable from the normal background radiation under dynamic conditions.

4. The device is most sensitive to a source located close to either of two opposing units rather than on the center line of the test channel.

5. A decrease in detector sensitivity results when opposing units are moved apart.

6. The location of the radioactive source within the test channel is very critical in the case of a wide test channel but of greatly decreased significance in the case of a narrow test channel (2 feet wide).

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TABLE I

EFFECT OF SOURCE INTENSITY

SOURCE INTENSITY	TWO-TANK COUNT RATE *	FOUR-TANK COUNT RATE *
0.0 μc	0	0
0.1 μc	1590	2390
0.2 μc	2620	3970
0.3 μc	4990	6330
0.4 μc	6160	8810
0.5 μc	7210	10550
0.6 μc	9240	13000
0.7 μc	11600	14200
0.8 μc	11400	16900
0.9 μc	13400	17800
1.0 μc	16200	21400
1.1 μc	17300	24400
1.2 μc	17600	24800
1.3 μc	20400	27400
1.4 μc	21600	28200
1.5 μc	23600	31100

Source location was at X=0, Y=-15, Z=30 in 2-foot wide test channel.

* Counts/minute corrected for background.

TABLE II

SYSTEM RESPONSE

UNDER DYNAMIC CONDITIONS

CONVEYOR SPEED	BACKGROUND-CORRECTED COUNT RATE		
	COUNTS/MINUTE		
FT/SEC	0.2 (microcurie)	0.5 (microcurie)	1.0 microcurie)
0	4350	10350	21600
0.2	3790	9390	19550
0.4	3630	9110	18100
0.6	3420	7620	17600
0.8	2870	6410	14800
1.0	2480	5920	13700
1.5	2050	4060	11100
2.0	1060	1980	5820

TABLE III

SHIELDING EFFECT OF COMMON MATERIALS

TEST ARTICLE AT X=0, Y=-15, Z=30 IN A 2-FOOT WIDE TEST CHANNEL

SOURCE INTENSITY - 0.2 mc

MATERIAL	COUNT RATE METER READING Background Correct
1. Unshielded.	4180 cpm
2. Source submerged in the center of a water filled rectangular plastic container 1' X 1' X 1'.	1020 cpm
3. Source submerged in the center of a water filled cylindrical plastic container 5" dia. X 5' deep.	2530 cpm
4. Source encased in the center of a container composed of common 2½" thick building bricks.	1890 cpm
5. Source encased in the center of a wood container with 1½" thick walls.	2860 cpm
6. Source encased in the center of a 1' X 1' X 0.5" cardboard box filled with tightly packed newspaper.	2670 cpm
7. Source placed in the center of a 9" X 17" X 26" leather suitcase filled with tightly packed folded rags.	3520 cpm
8. Source placed in the center of an 18" X 14" X 5" vinyl attache case filled with books.	2360 cpm
9. Source placed in the center of a 1' X 1' X 1' cardboard box filled with packed sawdust.	3290 cpm
10. Source placed in the center of a 1' X 1' X 1' cardboard box filled with magazines.	2080 cpm

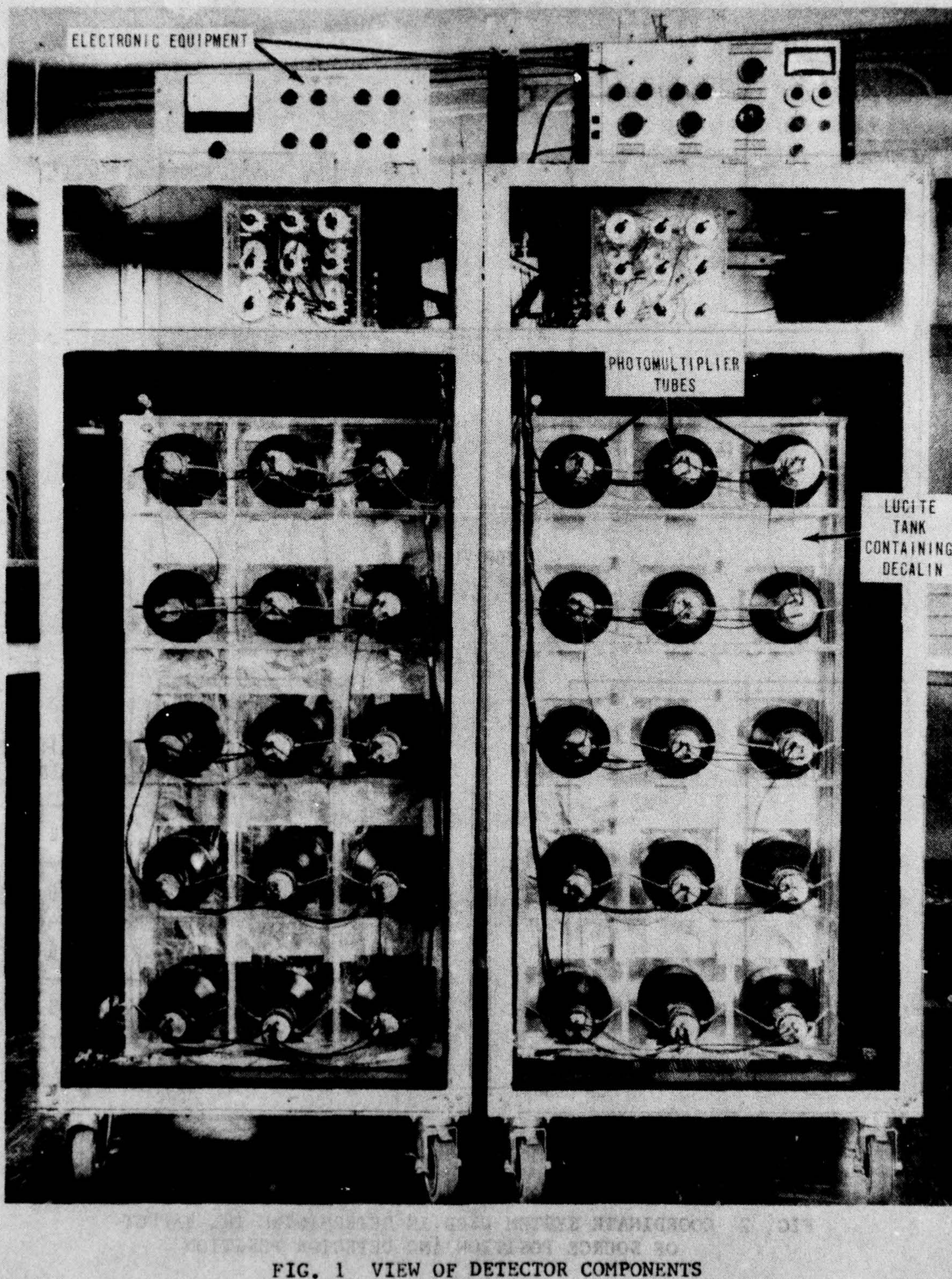

FIG. 1 VIEW OF DETECTOR COMPONENTS

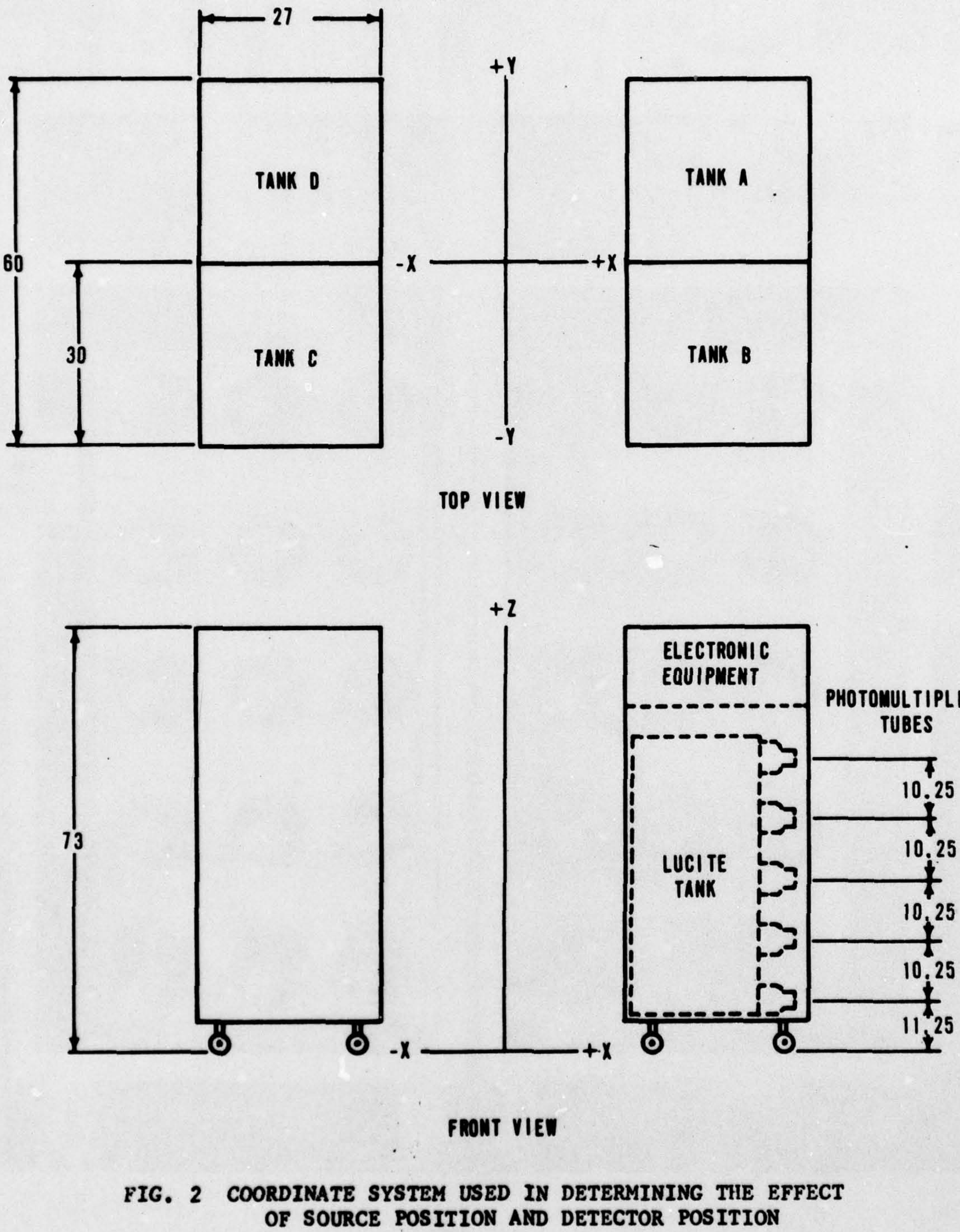

FIG. 2 COORDINATE SYSTEM USED IN DETERMINING THE EFFECT OF SOURCE POSITION AND DETECTOR POSITION

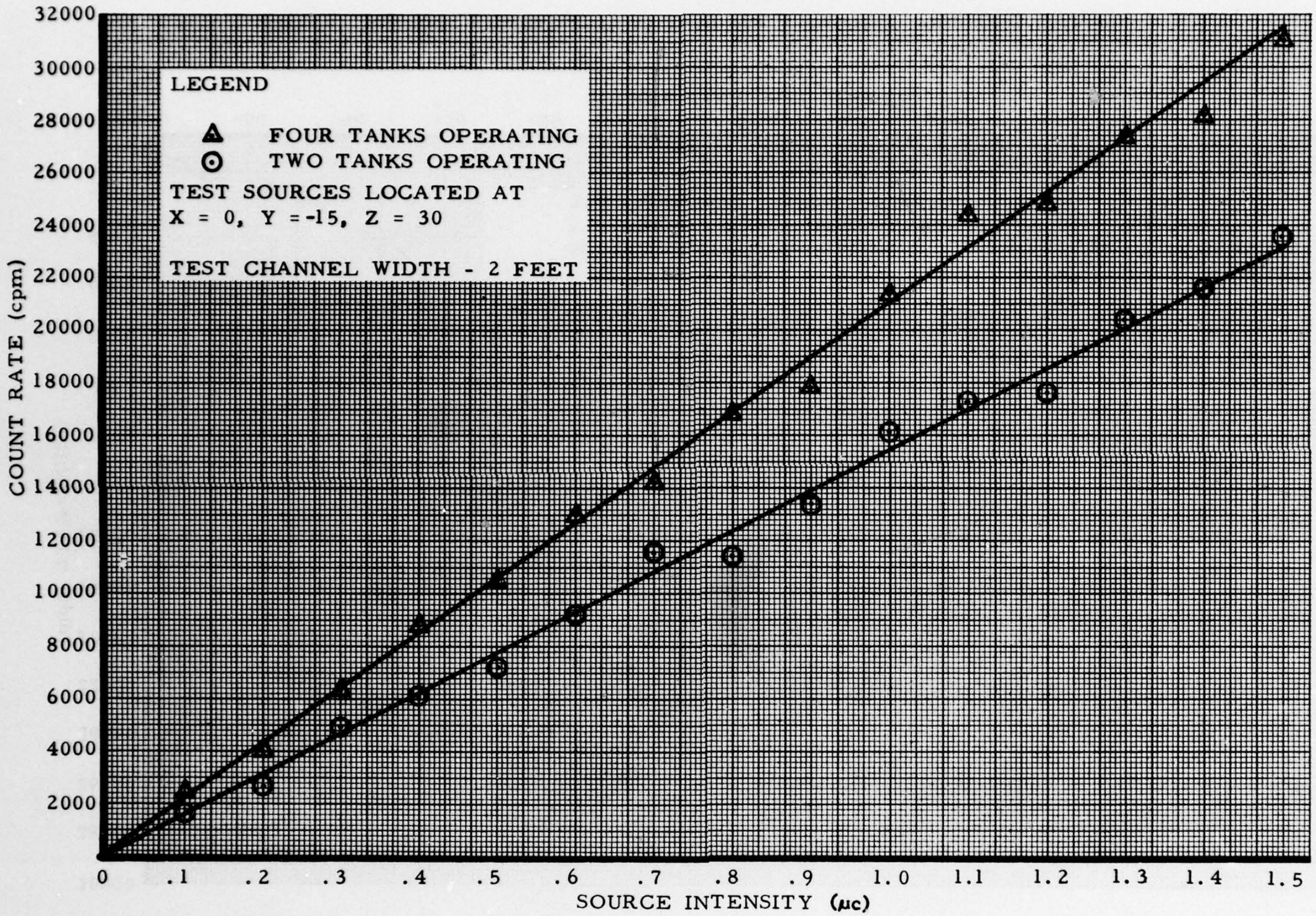

FIG. 3 SOURCE INTENSITY VERSUS COUNT RATE METER READING

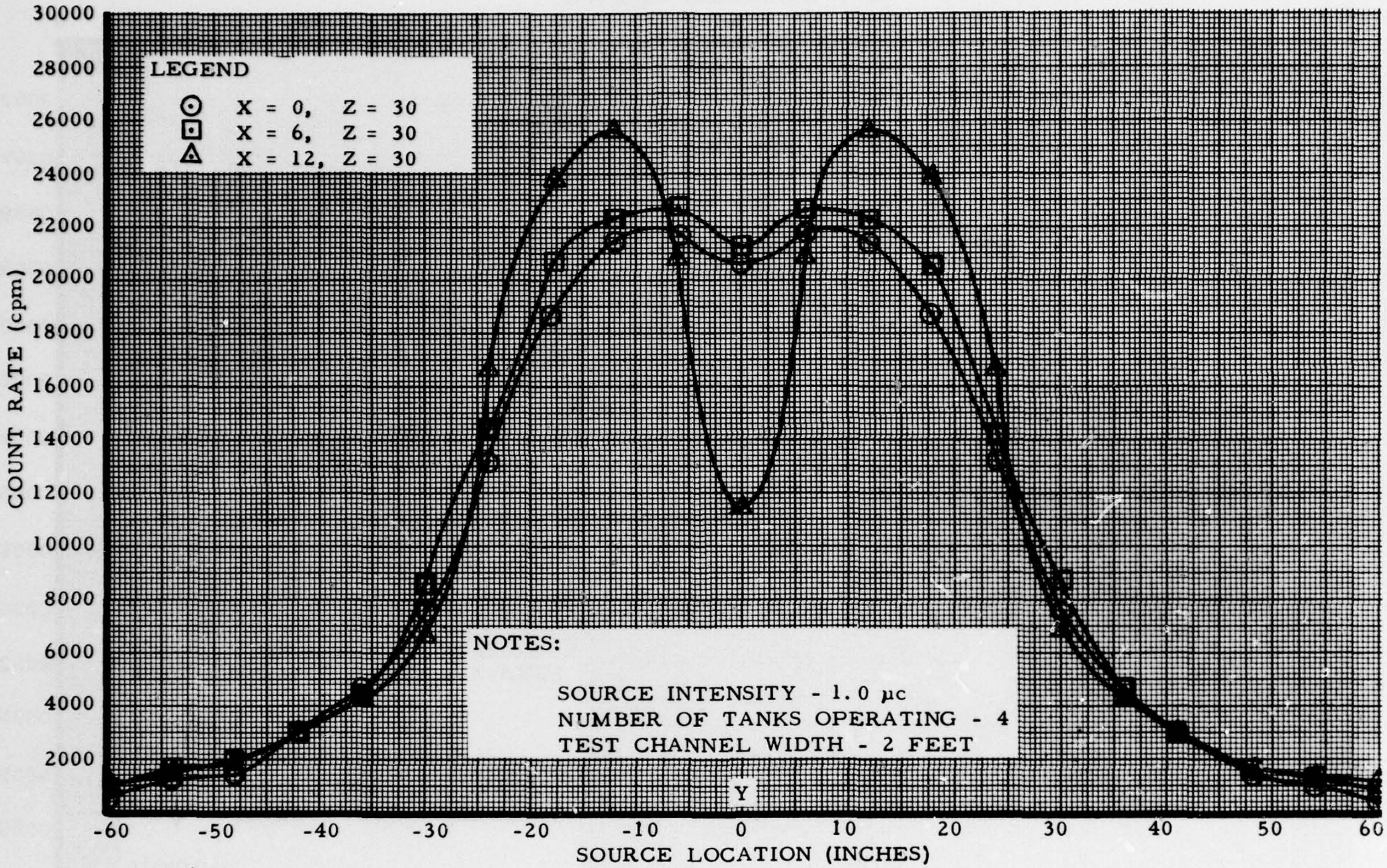

FIG. 4 TRAVERSE MEASUREMENTS AT Z=30 FOR A TWO FOOT WIDE TEST CHANNEL

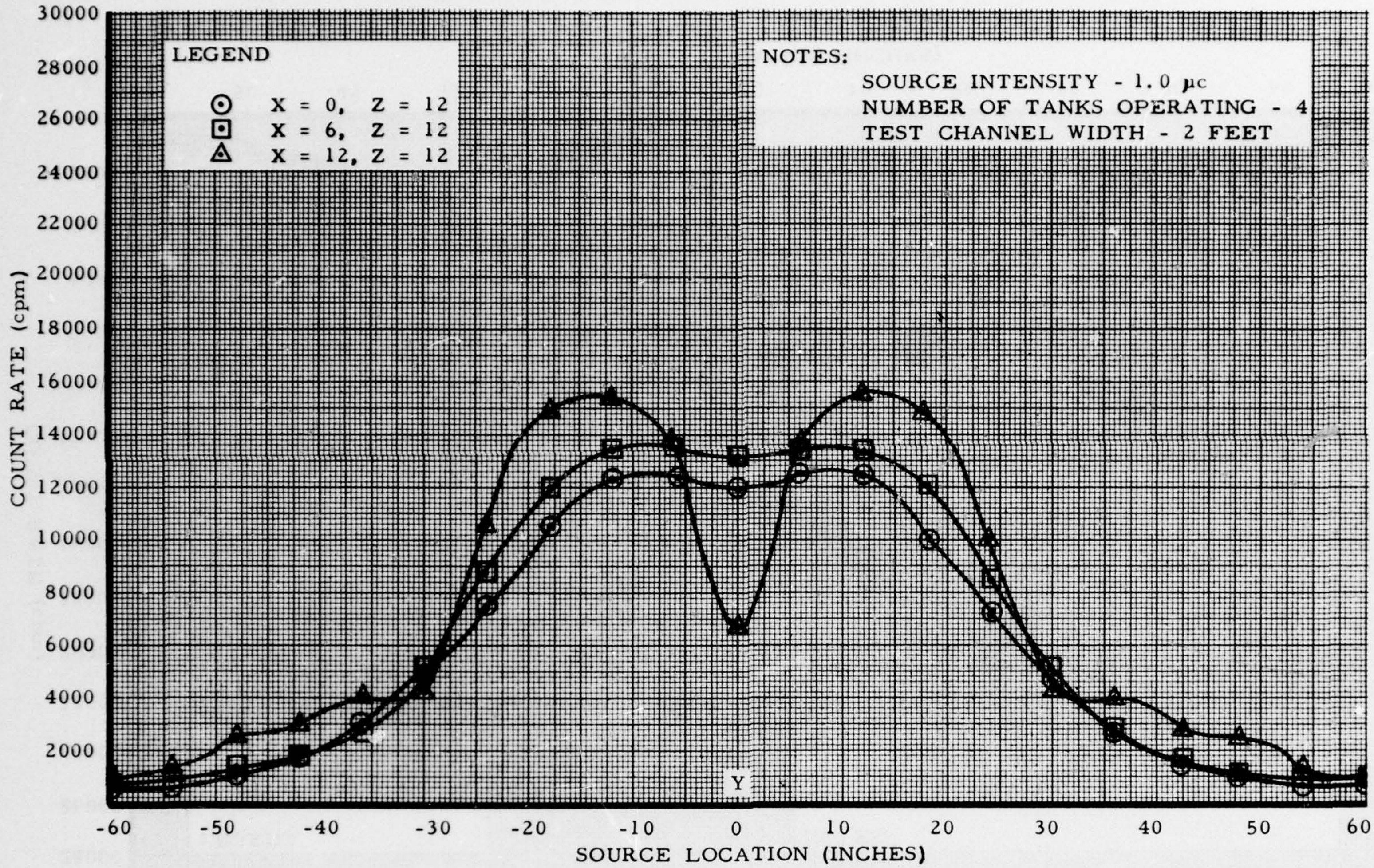

FIG. 5 TRAVERSE MEASUREMENTS AT Z=12 FOR A TWO FOOT WIDE TEST CHANNEL

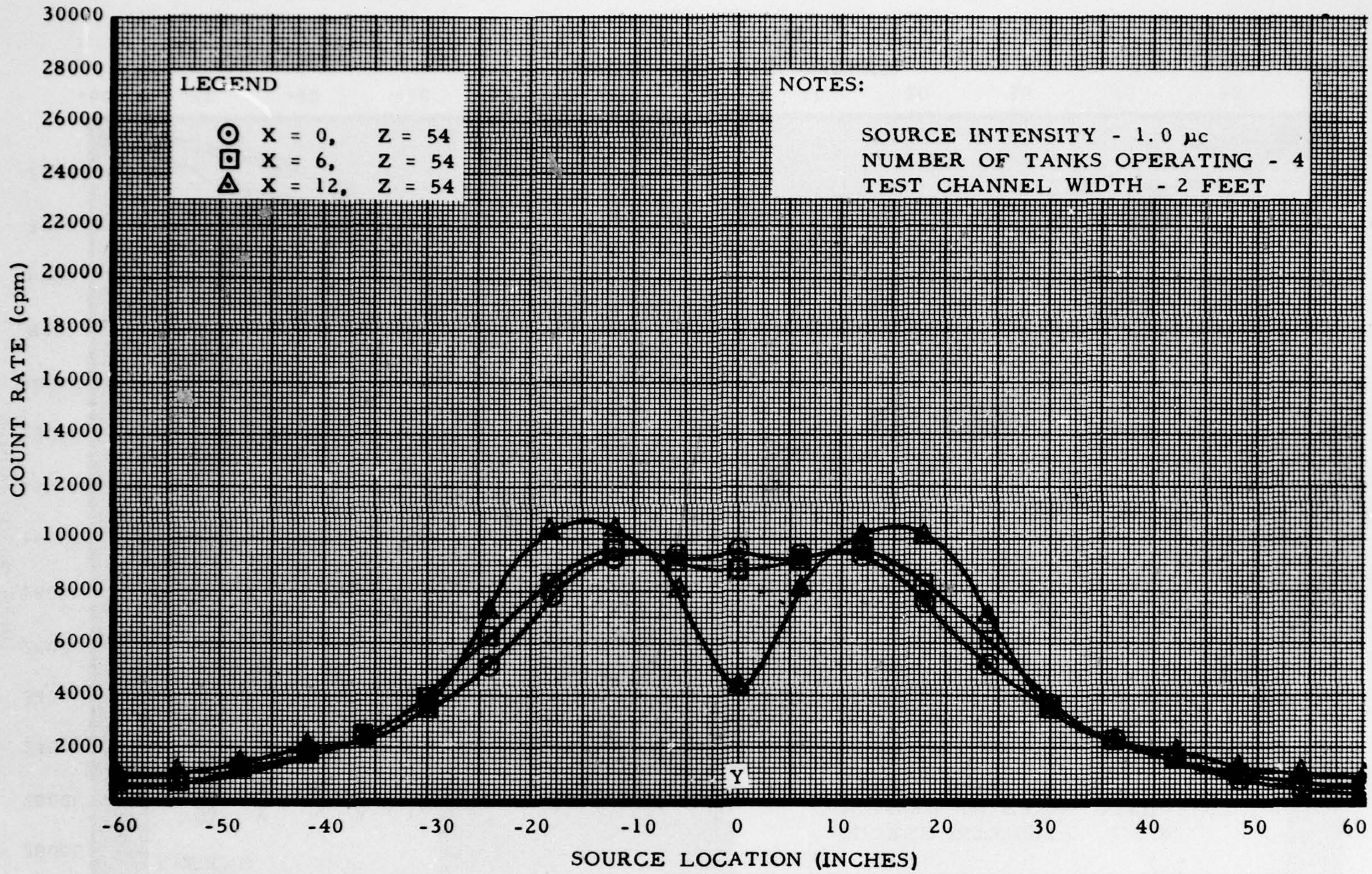

FIG. 6 TRAVERSE MEASUREMENTS AT Z=54 FOR A TWO FOOT WIDE TEST CHANNEL

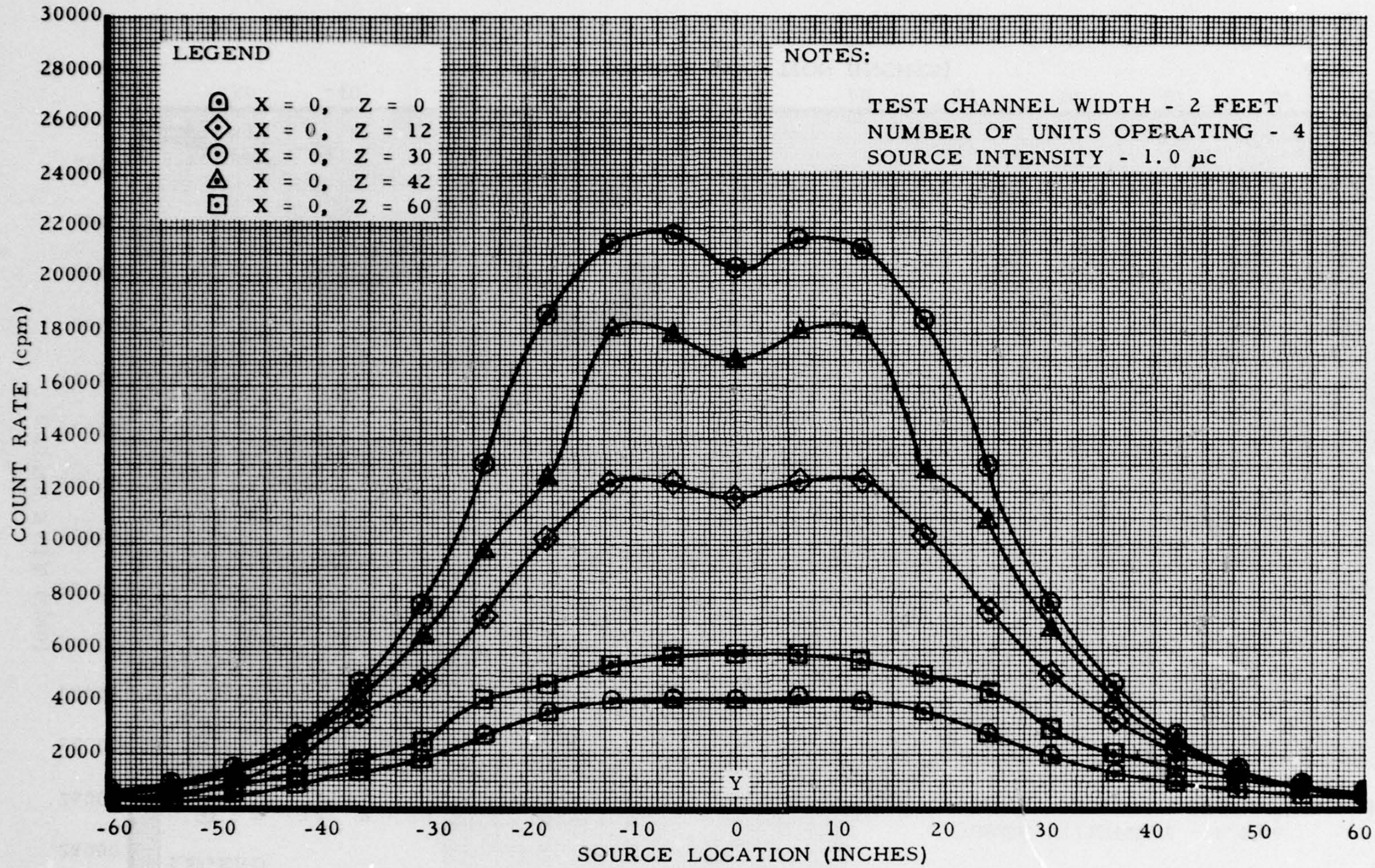

FIG. 7 VARIATION IN COUNT RATE METER READING ALONG THE Y-AXIS AT X=0 FOR VARIOUS ELEVATIONS IN A TWO FOOT WIDE TEST CHANNEL

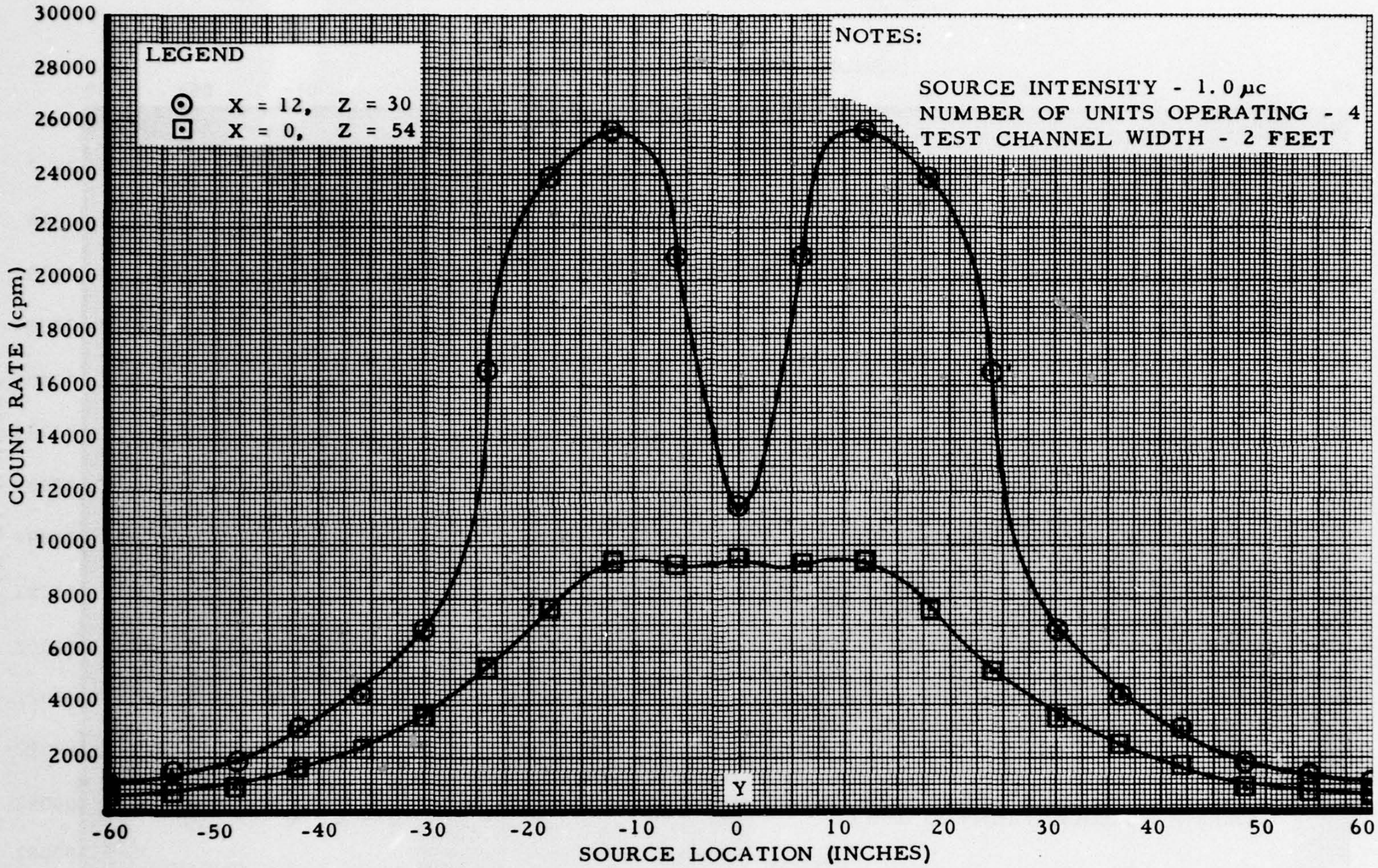

FIG. 8 MAXIMUM AND MINIMUM TRAVERSE CURVES FOR A TWO FOOT WIDE TEST CHANNEL

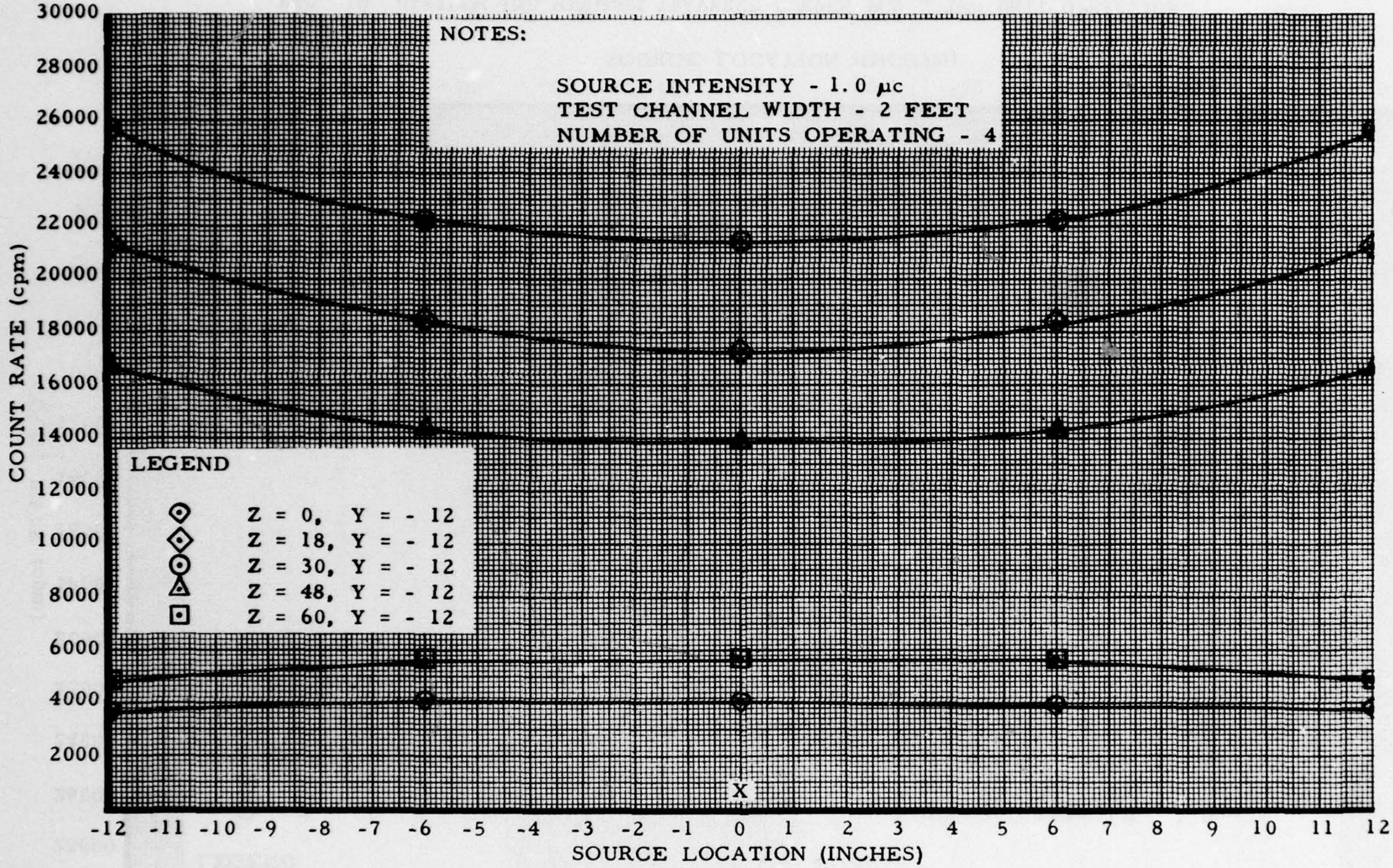

FIG. 9 VARIATION IN COUNT RATE METER READING ALONG THE X-AXIS AT Y=-12 FOR VARIOUS ELEVATIONS IN A TWO FOOT WIDE TEST CHANNEL

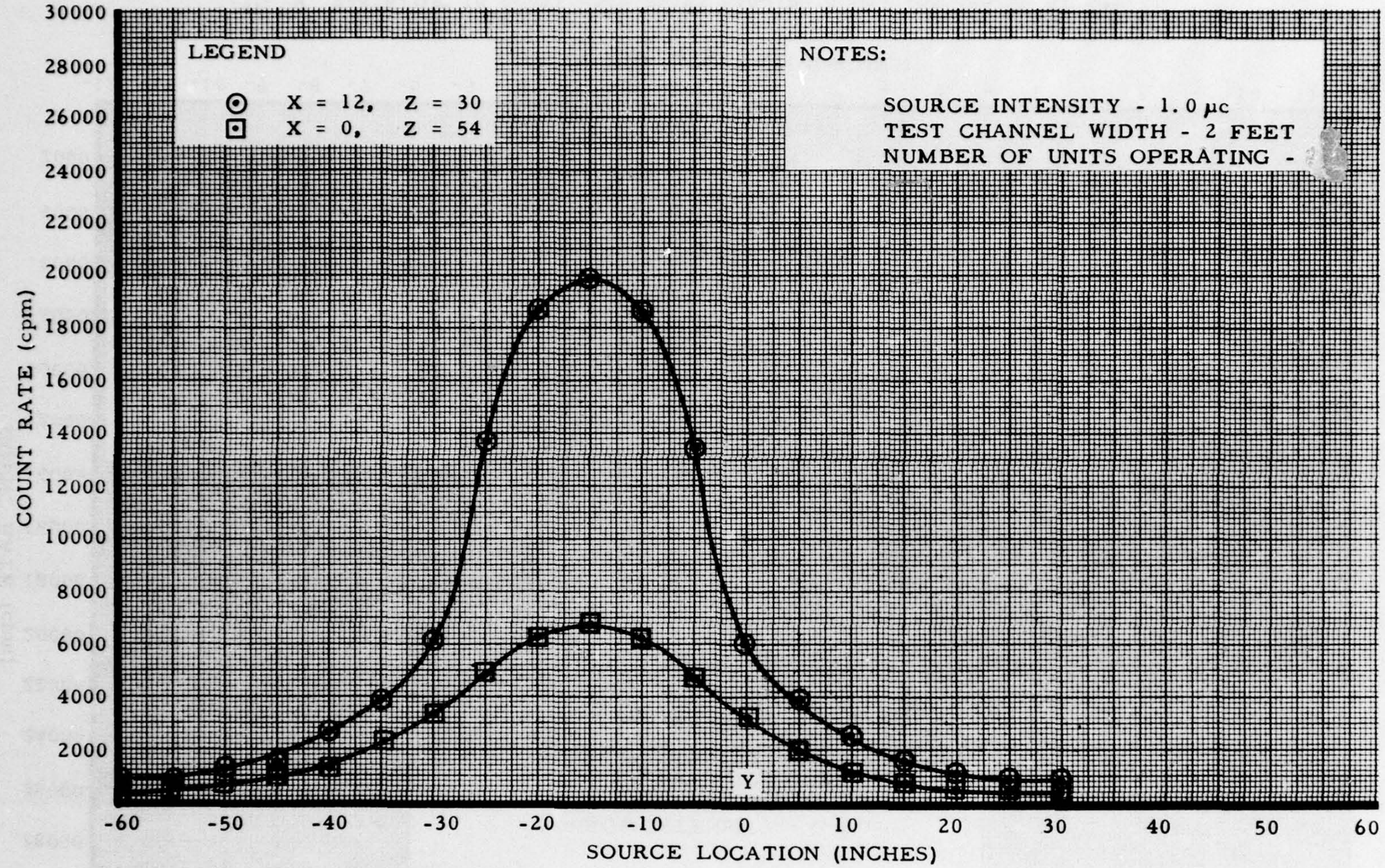

FIG. 10 MAXIMUM AND MINIMUM TRAVERSE CURVES FOR A TWO UNIT OPERATION

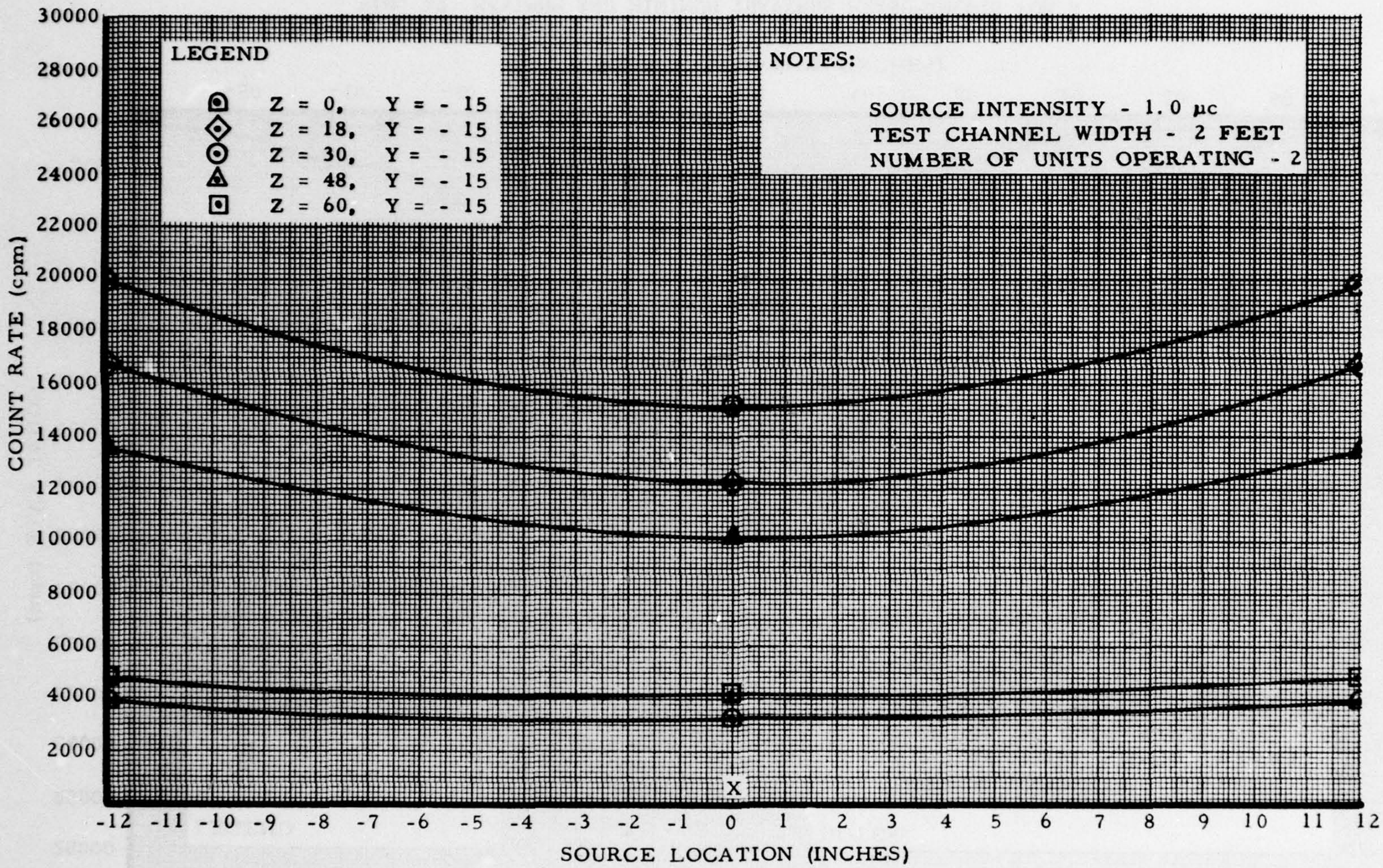

FIG. 11 VARIATION IN COUNT RATE METER READING ALONG THE X-AXIS AT Y=-15 FOR A TWO UNIT OPERATION

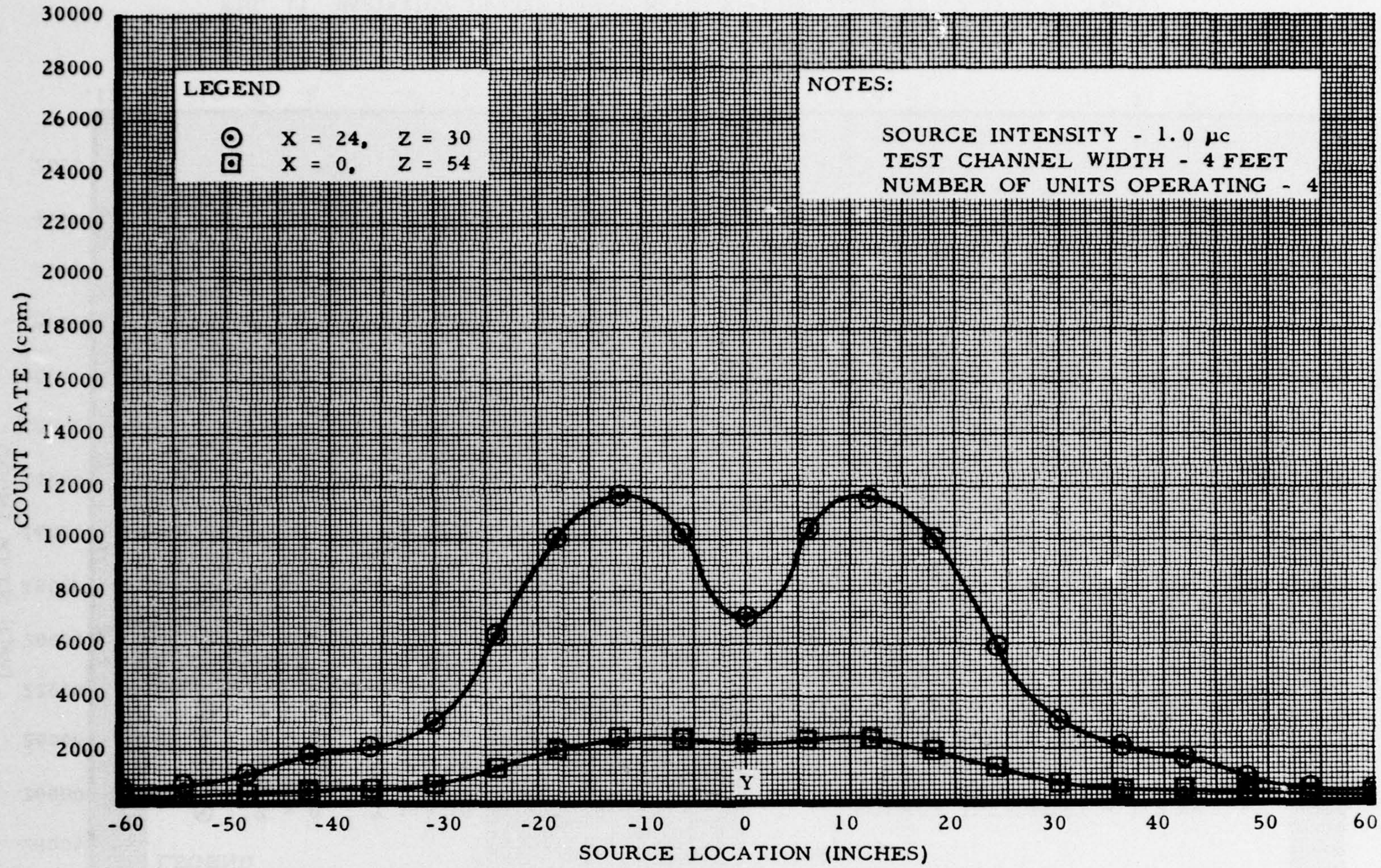

FIG. 12 MAXIMUM AND MINIMUM TRAVERSE MEASUREMENTS FOR A FOUR FOOT WIDE TEST CHANNEL

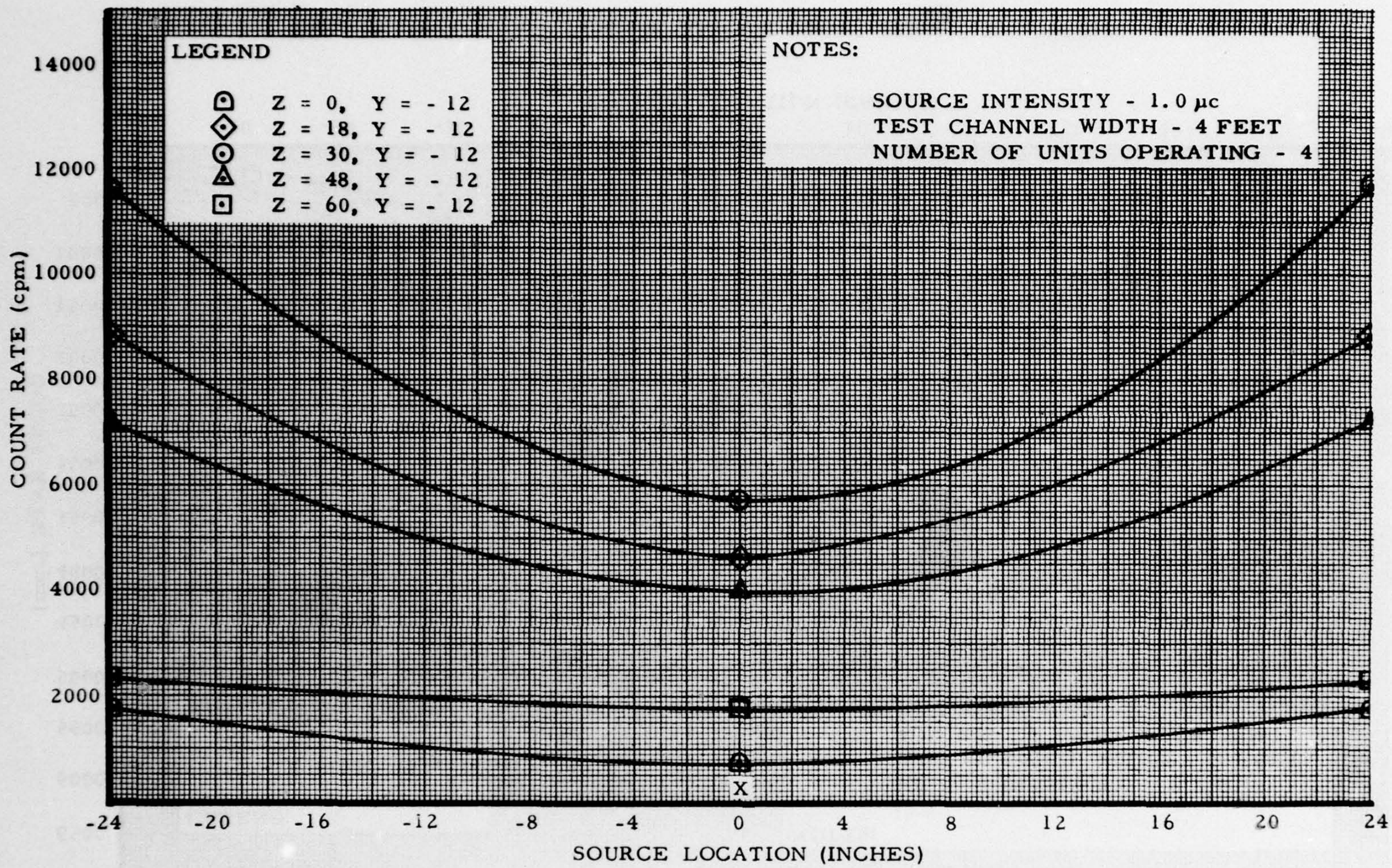

FIG. 13 VARIATION IN COUNT RATE METER READING ALONG THE X-AXIS FOR A FOUR FOOT WIDE TEST CHANNEL

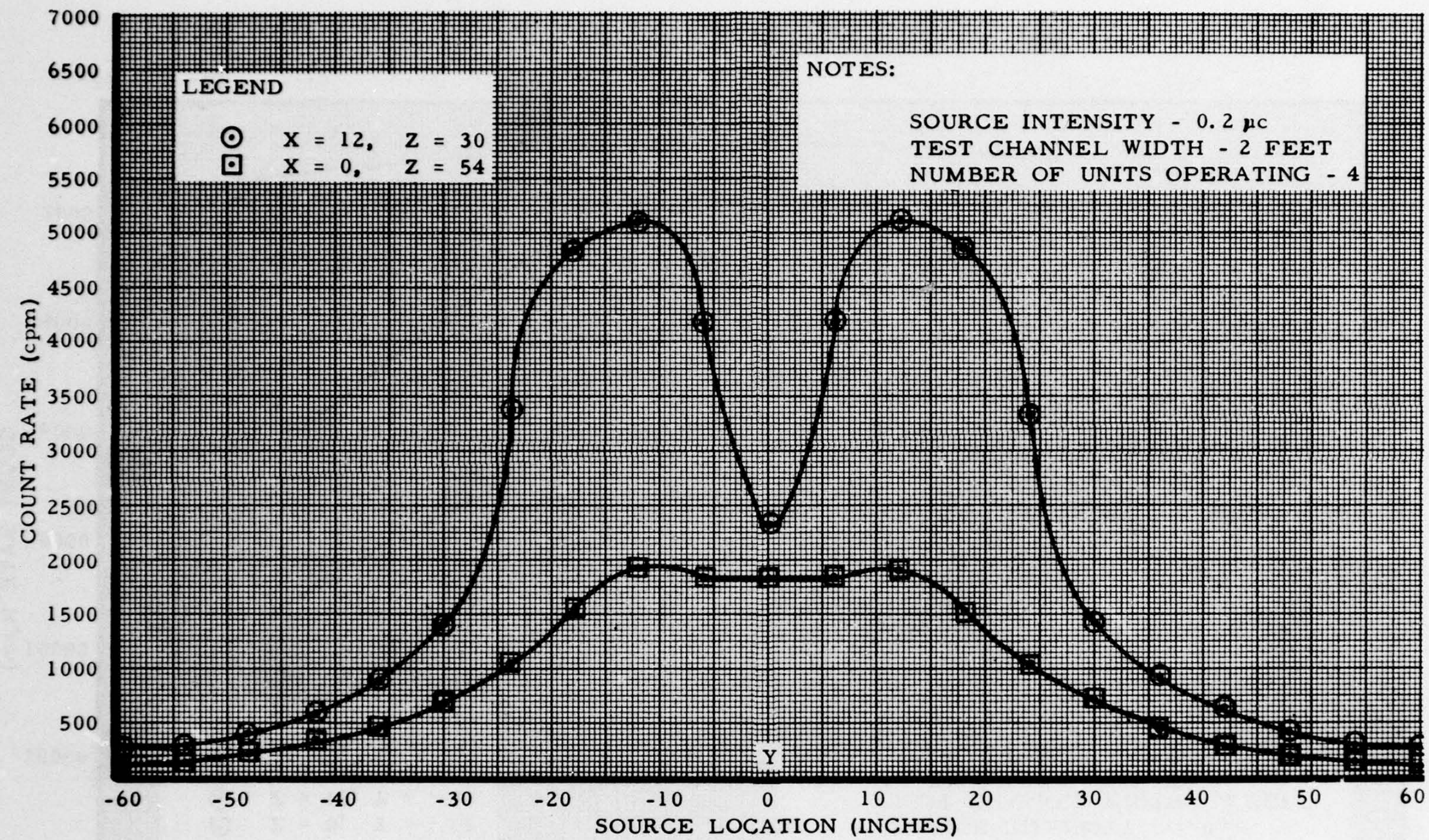

FIG. 14 MAXIMUM AND MINIMUM TRAVERSE CURVES FOR A 0.2 μc SOURCE

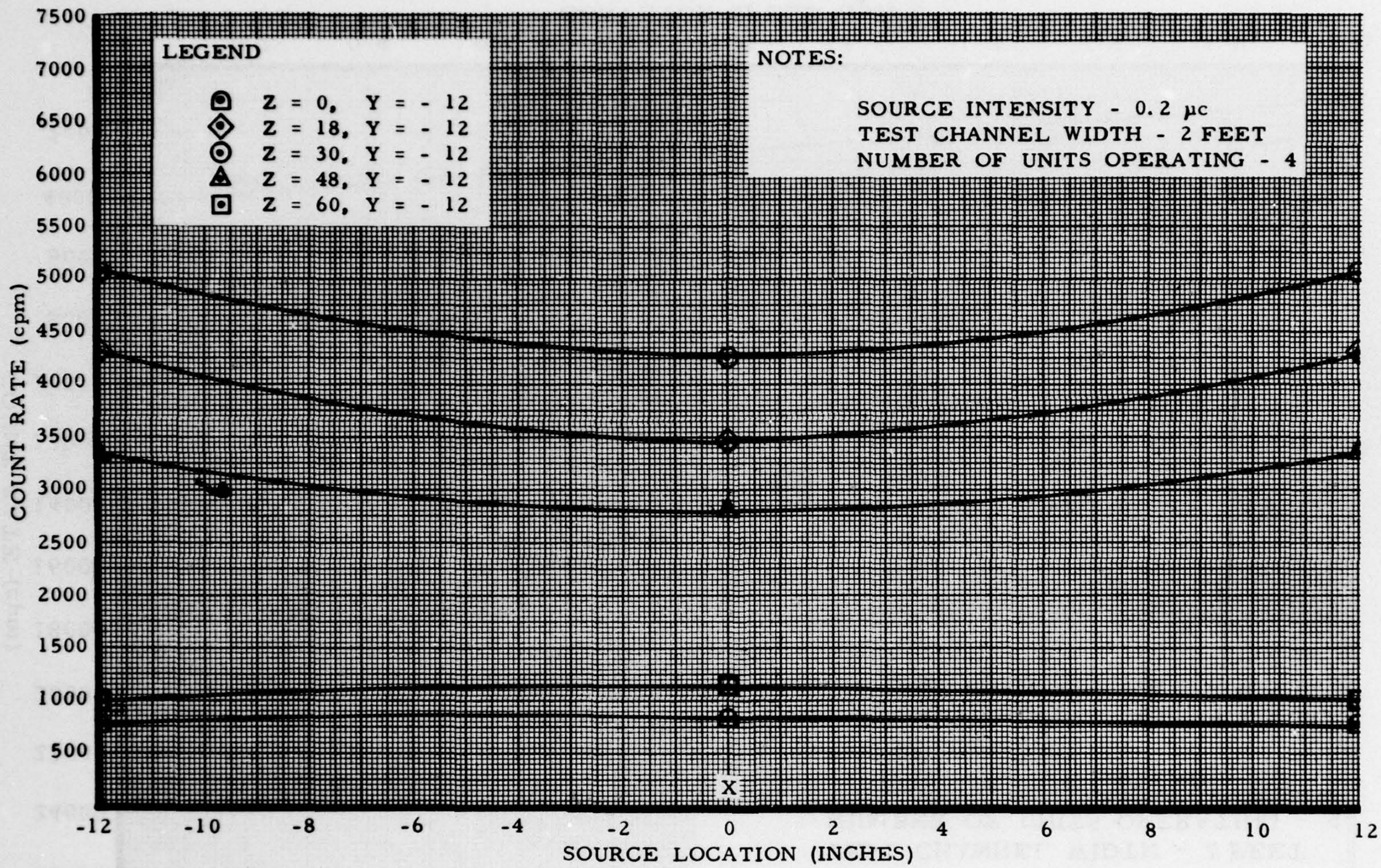

FIG. 15 VARIATION IN COUNT RATE METER READING ALONG THE X-AXIS AT Y=-12 FOR A 0.2 μc SOURCE

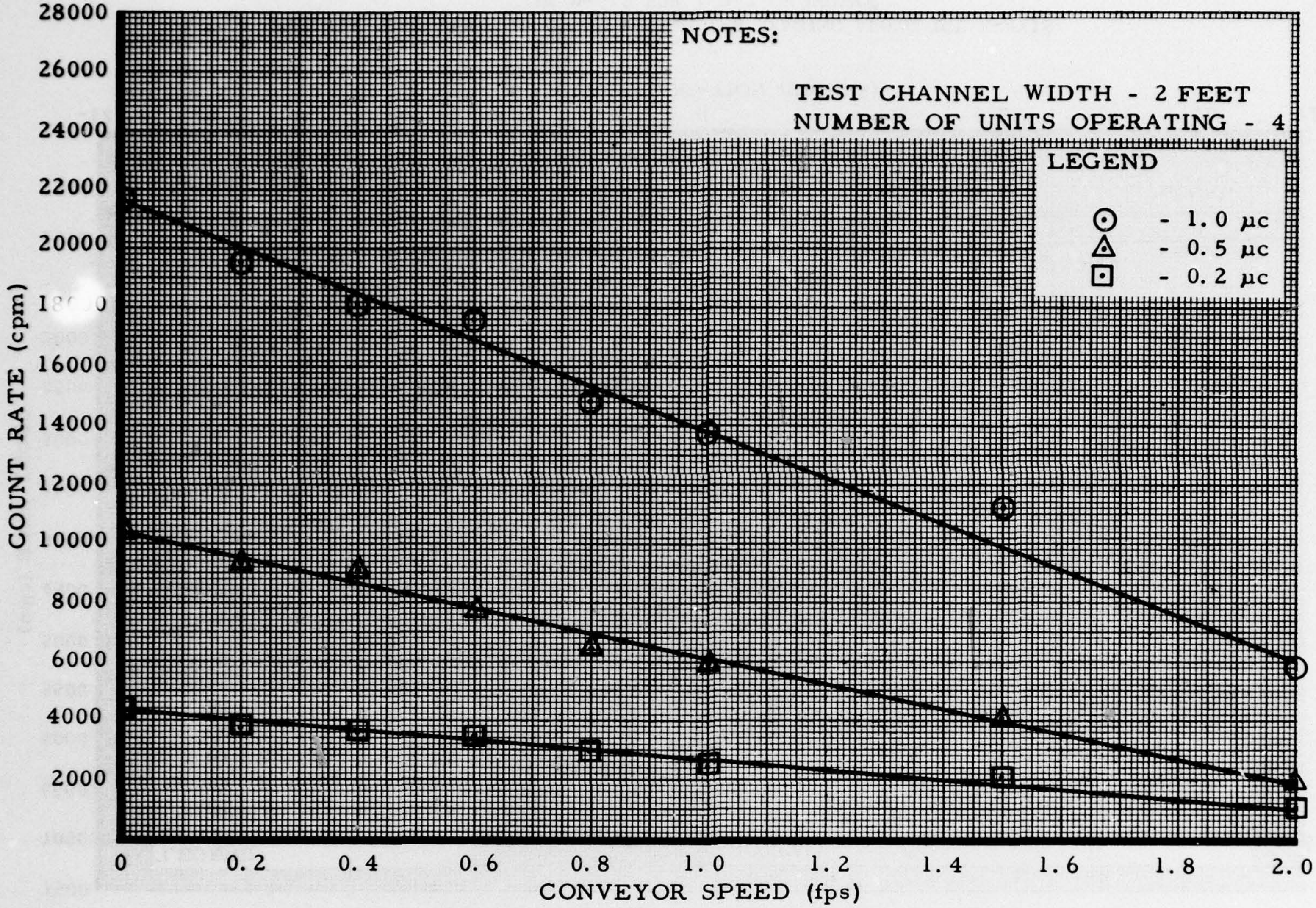

FIG. 16 SOURCE SPEED VERSUS COUNT RATE METER READING